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ITALIAN PETROLOGICAL SKETCHES.

I. THE BOLSENA REGION.

Introduction.—The number and easy accessibility of its volcanoes render Italy an enticing field for the geologist. The peculiar characters of their eruptive rocks, which are rich in potash, and in which leucite is a most common mineral, render them of special interest to the petrologist. It would seem, however, judging from a quite extensive survey of the literature, that the country has been rather neglected in recent years by petrologists ; since, except for a comparatively small number of modern papers describing limited districts, we must turn for many of our descriptions to the writers of more than a quarter of a century ago. Few attempts also have been made to correlate the facts in our possession for the purpose of determining the general petrological characters of the Italian province.

In the autumn of 1894 the writer had the opportunity to pay brief visits to most of the Italian mainland volcanoes and make collections of their representative rocks. A study of the specimens collected revealed so many new and interesting features that it was decided to publish a series of short papers on various Italian volcanoes. In these the separate rocks will be described, and some general conclusions which have been drawn from their study will be presented in a final paper. The work of the modern school of Italian petrographers will be used and quoted extensively, since it is comparatively little known to the outside world. As the time devoted to each volcano was all too brief these papers must be sketches merely, and will be predominantly petrological in character.

I. THE BOLSENA REGION.

Bibliography.—The work of the early geologists—such as Breislak, Brocchi, Pareto and Pilla—need not detain us, as they are of little interest in the present connection. We may note, however, that Pareto in 1844 pointed out three centers of activity, Latera, Torre Alfina and Montefiascone, around lake Bolsena.

Vom Rath[1] in 1868 gave a detailed description of the region. His paper is largely topographical, with some descriptions of the tuff and lava beds and a couple of analyses. He does not consider the lake as the remains of one large crater, but thinks that it is due to a sinking of the surface (*Einsenkung*), and that the circle of hills was produced by eruptions at different points around this tract.

Stoppani[2] in 1873 gives a description of the volcano, in the course of which he expresses his belief that the lake is in reality the site of a vast crater, slightly enlarged by erosion; at the same time recognizing the existence of parasitic cones, of which he gives Monte Rado near Bagnorea as an example.

In 1888 Verri[3] published a geological sketch of the region, the rocks collected by him being handed over to Ricciardi for chemical analysis and to Klein for petrographical description. After a brief historical and topographical description he discusses the order and epoch of the eruptions, and then describes in detail the various eruptive centers around the lake. The origin of this he holds to be that given by vom Rath. He considers that the tuffs of the region were erupted in the condition of mud —a conclusion, it may be added, which is strongly combated by other Italian geologists.

Klein's[4] article is composed of petrographical descriptions of Verri's specimens, which include most of the prominent rocks of the region. Though the descriptions are short and concise, they give a very good idea of the rocks; and I am happy to say that my own studies of specimens from the same localities substantiate Klein's descriptions in almost all points. The paper

[1] VOM RATH, Zeit. d. d. geol. Gesell., XX, 265–294, 1868.

[2] STOPPANI, Corso di Geologia, Milano, 1873, III, 376, 386.

[3] VERRI, Boll. Soc. Geol. Ital., VII, 49–99, 1888.

[4] KLEIN, Neu. Jahrb., B. Bd., VI, 1–35, 1889.

also contains the complete set of Ricciardi's analyses, which were published by him elsewhere.[1]

In the same year Moderni[2] published a short paper on the trachyte and tuff of Rispampani near Toscanella, which lies to the south of Lake Bolsena. He states that the trachyte forms a dome resting on Eocene beds. The trachytic tuff is remarkable for its radiating columnar structure, and resembles a lava in external characters.

In an important paper on the extinct volcanoes of the northern Apennines de Stefani[3] takes Lake Bolsena as the type of the crater-lake eruptions and gives a detailed description on the basis of his own observations. He differs from Verri in several points, notably in regard to the genesis of the lake, which he regards as a large central crater, at the same time recognizing the existence of flank eruptions, and comparing the volcano to those of the Hawaiian Islands. The interesting general conclusions regarding the Italian volcanoes which he gives at the end of his paper will be noticed elsewhere.

The last writer to treat of the region is Bucca[4] who gives short petrographical descriptions of a number of the leucite rocks.

Topography.—The center of the region is Lake Bolsena, which lies northwest of Rome and southwest of Orvieto, in Lat. 42° 35′ and Long. 12° 20′ E. Its shape is quite regularly elliptical, the major axis running north and south. Its dimensions are 13 by 10 kilometers, with a surface area of about 112 square kilometers, being thus the largest crater-lake in Italy, and one of the largest in the world. The surface of the lake is 305 meters above sea level, and the greatest observed depth is 140 meters. The two small islands of Bisentina and Martana rise a few meters above the surface in the southern and southwestern parts of the lake. They are composed chiefly of tuff and seem to be the remains of small volcanic cones.

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[1] RICCIARDI, Gazz. Chim. Ital., Palermo, 1888.

[2] MODERNI, Boll. Com. Geol. Ital., X, 19–25, 1889.

[3] DE STEFANI, Boll. Soc. Geol. Ital., X, 499–537, 1891.

[4] BUCCA, Rivista Min. e Crist., 18–30, 1893.

Surrounding the lake and sloping steeply down to its waters (leaving only a narrow shore margin), is a girdle of hills whose most elevated points on the north are 600 to 680 meters above sea level, and hence 300 to 375 above the surface of the lake. Towards the south they diminish in height, a feature which this cräter possesses in common with others of Italy.

These hills are made up of volcanic material, chiefly leucitic lavas and tuffs, though to the north of the lake considerable "trachyte" is found. In places fine sections of superposed tuffs and lava streams are exposed, and in the latter a columnar structure is sometimes very well developed. From the crest encircling the lake the surface slopes gradually down on all sides, till the volcanic ejectamenta thin out in tuffs resting on the Sub-Apennine pliocene marine marls.

The whole district occupied by volcanic material thus forms a low lenticular mass (with the lake in a hollow at the center), whose outer sides slope at angles of 12° to 15°. Its diameter is about 40^{km} and its total area some 1300 square kilometers, as has been estimated by Stoppani and Verri. Erosion of the soft tuffs has cut up the surface to a great extent, producing characteristic radiating ravines, which de Stefani compares with our western canyons in miniature, and forming isolated buttes such as those on which the towns of Orvieto and Civita di Bagnorea are so picturesquely situated.

Lying immediately to the west of Lake Bolsena is another depression, or rather plain surrounded by a girdle of hills, also of least height to the south, its circle impinging on that of the Bolsena Crater. This crater, which is known as the Latèra Crater, is smaller than that of Lake Bolsena, having a diameter of about 7^{km}. The small Lake Mezzano, which occupies part of the area, preserves well the form of a crater, and may be looked upon as the site of the last eruption of the Latèra volcano. This seems, from the descriptions, to be a distinct eruptive center, though nothing is said by any of the writers mentioning it as to its age relative to that of the Bolsena volcano. It would seem, however, to be the more recent, since the original crateriform character of both the exterior Latéra and interior Mezzano craters are better preserved than in the case of Bolsena; and also because it is, according to Stoppani, at present in a solfataric state.[1] The lavas of Latéra are entirely leucitic, so far as is known, no trachytes having yet been found at this center.

To the north of the Bolsena Region lie a number of small isolated volcano vents, such as the "trachytic" Monte Amiata and the basaltic hill of Radicofani. To the east are the Tertiary deposits flanking the main line of the Apennines, and to the south lies the closely similar volcanic Viterbo Region, which will form the subject of the next paper.

As to the character of the eruptions little need be said here, though I may insert de Stefani's summing up of the subject. He says:[2] "In conclusion we can hold that the volcano, submarine in the beginning, became later subaërial and erupted in the midst of a low and swampy region like the Maremme (marshes) of the present day in the same country." He thinks that the latest eruptions of tuff were dry and probably fell on dry land.

Discussion of the origin of the lake must be deferred to another place, since the existence of such crater-lakes is a feature common to several of the regions to be described. We may note, however, that there are two prominent theories. One is that of vom Rath and Verri, who regard the lake as a sunken tract, the sinking being due to the ejection of material from various points which forms the hills surrounding it. The other is that held by Stoppani and de Stefani, who consider the lake as the volcanic center, the remains of a large crater which has been enlarged by explosions and the falling in of its walls; and from which was ejected the greater part of the volcanic material, small flank eruptions also adding to the mass of the volcano. I may remark, in anticipation, that the weight of evidence and analogy is in favor of the latter theory.

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[1] As I did not visit this western part of the region I cannot say whether one crater circle cuts the other or not, and I can find no mention of this point in the literature.

[2] DE STEFANI, op. cit., 526. He notes that von Buch expressed the same view about 1810.

As to the period of the eruptions de Stefani points out that in certain places, especially in the northern part, volcanic products alternate with marine fossil-bearing strata of the late Pliocene; and we may assume that the main eruptions began in the Pliocene period. Both he and Stoppani also give reasons for thinking that the latest eruptions were contemporary with man and geologically very recent.[1]

PETROGRAPHY.

The petrography of many of the Italian volcanoes is involved in considerable confusion. This is especially true of the regions immediately around the great crater-lakes. We shall see that these large volcanoes erupted a great variety of lavas, while the smaller eruptive masses flanking this main line offer much less variety, each separate mass being largely composed of one definite type of rock. The Bolsena volcano is no exception to this rule, which de Stefani[2] has brought out very clearly.

The confusion results partly from the tendency which many of the types have, especially among the leucitic rocks, of grading into one another; and partly from the presence of peculiar non-leucitic rocks which do not fit exactly into any place in our scheme of classification, and whose naming is largely a subjective matter.

It has lately been pointed out by Brögger[3] and Pirsson[4] that at the present stage of the science we must recognize the quantitative chemical and mineralogical relations as well as the qualitative. Brögger[5] has also made an able plea for the recognition of transition groups, the importance of which in our classification he brings out very clearly. With Brögger's views on the subject I, like Pirsson, heartily concur; and his principles will be recognized in the classification of the rocks which we shall examine. This will involve the proposal of some new names, but the baptismal rite will be indulged in as sparingly as may be.

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[1] STOPPANI (p. 384) quotes Gualterio as arguing for the probability of the formation of the Bolsena volcano during the paleolithic period.

[2] DE STEFANI, op. cit., 550.

[3] W. C. BRÖGGER, Gest. d. Grorudit-Tinguait Serie, Kristiania, 92, 1894.

[4] L. V. PIRSSON, Am. J. Sci., L, 478, 1895.

[5] BRÖGGER, op. cit., 93, and Eruptionsfolge bei Predazzo, Krist., 1895.

For the present we must confine ourselves to the Bolsena volcano, and may say that two prominent types exist, the trachy-andesitic and the leucitic rocks. Even these two prominent types grade into one another to a slight extent, though they can as a rule be readily distinguished. In the following pages I shall describe my own specimens, turning to Klein and Bucca for descriptions of rocks which I was unable to collect. The tuffs and the metamorphosed ejected blocks will not be touched upon. Ricciardi's analyses cover the ground so completely that only one fresh analysis was made, of the important Bolsena "trachyte." Vom Rath's analyses and the best of Ricciardi's will be inserted later.

Vulsinite.—Vom Rath first called attention to the abnormal chemical character of the "trachyte" of Bolsena, though he speaks of it as containing no plagioclase, probably owing to the rarity of the multiple twinning. As will be seen from Klein's descriptions and my own, and from the analyses, the peculiar "trachytes" of the region are remarkable; mineralogically for their richness in plagioclase and the frequent occurrence of olivine as an essential constituent, and chemically for their low silica and high lime and magnesia. Therefore they are not trachytes proper, but correspond to the trachy-dolerites of Abich[1] and Hartung,[2] and to some of the andesitic-trachytes of Rosenbusch,[3] and we shall see that they may be regarded as effusive representatives of Brögger's abyssal monzonites. These olivine-free effusive rocks will be called by the name of *Vulsinite*,[4] from the Etruscan tribe, Vulsinii, formerly inhabiting this region. Those carrying olivine belong to a peculiar type which will be described in the next paper.

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[1] ABICH, Nat. n. Zusammensetz. d. Vulk. Bild., p. 101, 1841.

[2] HARTUNG, Azoren, Leipsig, p. 92, 1860. Cf. MUGGE, Neu. Jahrb., Vol. II, p. 201, 1883.

[3] ROSENBUSCH, Mikr. Phys. Vol. II, p. 600, 1887.

[4] The name Bolsenite has already been used by H. O. Lang (Min. Pet. Mit., XIII, 143, 1892) for one of his purely chemical groups, which embraces certain leucitic rocks.

These rocks are not very abundant in the region, and seem to be more common in the northern part than elsewhere. In certain cases they belong to the earlier eruptions, prior to those of the leucitic rocks. Purely alkali feldspar-trachytes seem to be unknown about this center, unless Moderni's trachyte of Rispampani belongs here, a point which his brief description does not permit us to decide. The plagioclase end of the series is represented by the augite-andesite of Monte Rado, which is also olivine-bearing.

The only specimens of vulsinite in my possession were collected from a small eminence on the eastern shore of the lake, immediately to the north of the small town of Bolsena. The locality is mentioned by Verri and de Stefani, and the rock is the same as that described by Klein (p. 8), with whose descriptions my specimens agree very closely. It is probably identical also with the trachyte of vom Rath (p. 291), though Nassini's quarry, whence he obtained his specimen, does not seem to be known at present. The rock belongs, as we shall see, to one of the earliest outflows.

Megascopically it is fine-grained and compact, with marked eutaxitic structure. The greater part is light ash gray, but mottled with spots and streaks of dark gray and yellowish brown. The structure here seems to be due to a mingling of magmas of somewhat different composition. Many glassy phenocrysts of feldspar, as well as smaller ones of augite and a few of biotite, are to be seen. The specific gravity is 2.534 at 25° C.

The feldspar phenocrysts are both alkali feldspar and plagioclase, the former in the majority but the latter quite common. Twinning, according to the Carlsbad law is not rare in the orthoclase, and one very perfect example of a Baveno twin was seen. While twinning is the rule with the plagioclase, yet multiple lamellæ are not often seen, and some untwinned crystals occur. Zonal structure is not frequent. The polarization color furnishes the readiest method of distinguishing between the two feldspars, that of the plagioclase in my sections, which are about $0^{mm}.2$ thick, reaching the light straw yellow of the first order. The difference in refractive index is also marked. Inclusions are not very abundant and are usually small spots of glass, with some augite, magnetite and apatite crystals. In the alkali feldspar phenocrysts inclusions of plagioclase of some size are occasionally seen, but the reverse was not noticed.

The examination of plagioclase phenocrysts in the slides was made with care and resulted in establishing the fact that they are anorthite. In a section cut approximately parallel to *c* (001) an optic axis emerges almost perpendicularly, and the angle of its extinction is 38° with the trace of the plane *b* (010). The alkali feldspar border (to be described presently), in this case extinguishes parallel to the same plane of the anorthite crystal. In another section cut parallel to *b* (010) the plane of the optic axes (determined by the emergence of an axis at the border of the field), formed an angle of —34° with the basal cleavage cracks, while the individuals of the Carlsbad twin extinguished at 29° and 30½° on each side of the twinning plane. The border around this crystal extinguished at an angle of 11° with the basal plane of the anorthite. This determination of the plagioclase as anorthite confirms Klein's observation of its basicity.

Apart from the composition of the plagioclase, the most interesting feature of the feldspars is brought out between crossed nicols. It is then seen that both alkali feldspar and anorthite phenocrysts are surrounded, almost without exception, by a border or mantle of alkali feldspar of late growth. This forms one individual around the phenocryst proper, as shown by the simultaneous extinction of the whole border. The outer edge is in general very irregular, ending with an uneven and often uncertain line against the groundmass; though here and there there has been an attempt to fill out the crystal form, resulting in quite sharply defined straight edges.

The mutual extinctions prove that the mantle is orientated like the nuclear crystal, and if the inner orthoclase crystal be twinned the twinning is continued uninterruptedly in the outer mantle. This is also true to some extent of the Carlsbad twinning of the anorthite crystals, and to a less extent of their multiple lamellæ due to albite twinning. Examination by Becke's method shows that there is no difference in refractive index between the substance of the mantle and the orthoclase phenocrysts, so that the two are to be distinguished (especially in ordinary light) by the differences of limpidity, while the higher index of the anorthite is strongly marked. The extinction angle of 11° in sections parallel to *b* (010) already mentioned indicates that the mantles are of soda orthoclase.

The border shows a well-developed micropoikilitic structure, since it contains like the groundmass many small augite and magnetite grains. In consequence of this there is scarcely any difference to be observed in ordinary light between the mantle and the surrounding groundmass, which seems to come quite up to the edges of the feldspar phenocryst.

Klein observed this feature in several rocks of the region, and Bucca likewise mentions a similar mantle in describing the leucite-phonolite of Bagnorea.

This mantle must be carefully distinguished from the phenocrystic crystal, as it is evidently the product of a distinct and later period of growth, and is almost identical with the holocrystalline groundmass. The only difference between the two is that under the influence of the pre-existing feldspar phenocryst the orthoclase substance crystallized as a single individual, the orientation of this later growth being determined by the nuclear crystal, and small crystals of augite and magnetite being included in a normal way. In the other part of the groundmass, away from the orientating influence of the large feldspar phenocryst, the orthoclase substance crystallized at many points as separate small individuals with diverse orientations, forming a normal trachytic groundmass.

The frequency with which plagioclase is surrounded by orthoclase in parallel position is well known and is noted by Rosenbusch,[1] though the present case differs somewhat from those mentioned by him. We do not have here the production of definite crystal forms, but rather the orientation of the groundmass into micropoikilitic patches, though the principle involved is the same in both. Similar mantles of alkali feldspar about labradorite have been observed by Iddings[1] in rocks of the Yellowstone Park, by Pirsson[2] in the syenite of Yogo Peak, Montana, by Merrill[3] in rocks from Montana, and by Kolenko[4] in trachyte from New Zealand.

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[1] ROSENBUSCH, Mikr. Phys., I, 638.

The borders in question are closely analogous to the micropoikilitic patches of quartz described by Miss Bascom,[5] Iddings[6] and Clements,[7] especially the last. Miss Bascom shows reasons for thinking the structure in the South Mountain rocks to be of secondary origin, while at the Electric Peak they are primary, as they also probably are in the Michigamme District according to Clements.

In the case before us the evidence is entirely in favor of their primary origin. As will be seen the phenomenon was observed in many other rocks of the Italian volcanic regions. These rocks are all comparatively recent lava streams, fresh and unaltered, so that there can be no appeal to metamorphic processes. The whole appearance of the border, with its included grains and its identity with the groundmass (except in its individual orientation), leaves no doubt that the effect is due simply to the orientating influence of the feldspar phenocrysts during solidification of the groundmass magma.[8]

The remaining phenocrysts are of augite and biotite, but offer few features worthy of note. In the normal gray vulsinite the augites—both phenocrysts and groundmass crystals—are of a pale olive green, while in the eutaxitic brown streaks they are of a bright golden-yellow color. The biotite phenocrysts are pale brown, irregular in outline and show without exception great "magmatic" alteration. The product is largely magnetite with little augite, and penetrates deeply and irregularly into the crystal. Magnetite is quite abundant, both in the groundmass and as phenocrystic grains. The groundmass is typically trachytic, and consists essentially of a holocrystalline cement of soda orthoclase flakes and laths, which latter are more abundant in the gray vulsinite than in the brown streaks. There is little evidence of flow structure. With these are numerous grains of yellow or greenish augite, magnetite grains and some apatite needles and grains of titanite. There are also seen some small crystals of a peculiar brown hornblende, which will be described at length later. No glass is present and the rock does not gelatinize with acids.

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[1] IDDINGS, JOURNAL OF GEOLOGY, III, 940, 941, 1895.

[2] PIRSSON, Am. J. Sci., L, 471, 1895.

[3] MERRILL, Proc. U. S. Nat. Mus., XVII, 645, 1894.

[4] KOLENKO, Neu. Jahrb., 1885, I, 9.

[5] F. BASCOM, this Journal, I, 816, 1893.

[6] J. P. IDDINGS, Electric Peak, 12th Rep. U. S. G. S., 589, 1892.

[7] J. M. CLEMENTS, this Journal, III, 814, 1895.

[8] Both Klein and Bucca consider them primary but late growths of orthoclase.

Here and there one sees coarse-grained, holocrystalline clusters of large augite, plagioclase, orthoclase and magnetite grains, which are probably segregations, as Klein suggests. The augite is generally bright golden-yellow, but a few pale green diopside grains are to be noticed. It is xenomorphic towards the feldspars, filling the interstices between them. The feldspars contain large dusty apatite crystals.

Three analyses of this rock are inserted here.

	1	2	3
SiO_2	59.22	57.97	58.21
TiO_2			Tr
Al_2O_3	18.56	17.65	19.90
Fe_2O_3		0.63	4.07
FeO	6.06	7.50	0.87
MnO		0.09	
MgO	1.12	1.71	0.98
CaO	2.96	5.53	3.58
Na_2O	4.87	1.50	2.57
K_2O	6.66	5.31	9.17
P_2O_5		0.42	not det.
Ignit.	1.14	1.82	0.74
	100.59	100.13	100.09

1. Vulsinite, Nassini's Quarry, Bolsena, VOM RATH, op. cit., 291.
2. " Bolsena, Ricciardi anal. KLEIN, op. cit., 8.
3. " Bolsena (665), Washington anal.

From the above description and analyses we may then define the *vulsinites* as effusive rocks *occupying an intermediate position between the trachytes and the andesites.* They are characterized mineralogically by the presence of alkali feldspar with a large amount of basic plagioclase (labradorite to anorthite) together with augite and diopside. Hornblende and biotite are not abundant in the type specimens, though they may be present in large amounts in other varieties, as will be seen later. Olivine is wanting, or if present is so in only accessory amounts. Chemically they are rocks of medium acidity, SiO_2, from about 55 to about 60 per cent., though it may run slightly above or below these figures. Alumina and iron are present in medium amounts, magnesia is low, lime rather high (3 to 6 per cent.), and alkalies (especially potash) high. Of the analyses above No. 3 may be regarded as typical. From an examination of this it is seen that after the formation of magnetite and pyroxene considerable lime is left over. Since part, if not most, of the alkali feldspar is a soda orthoclase and the amount of soda present is small this lime must go to form anorthite.

Klein describes very similar rocks which belong to the vulsinites. Those from Torre Alfina and San Lorenzo, north of Lake Bolsena, are very high in silica and lower in potash (according to Ricciardi's analyses) than we would expect (*cf.* anal. 5, p. 565). Their groundmass is brown, phenocrysts of glassy feldspar, biotite and augite are visible, and they seem not to be quite fresh. Among the phenocrysts sanidine largely predominates over the plagioclase, which is basic. Some olivine is present, but since the magnesia is low its quantity cannot be very great. The groundmass is very glassy, the base being brown through the presence of globulites. Orthoclase, plagioclase and magnetite are present in the groundmass, but augite is not mentioned. These rocks seem to resemble those of Monte Amiata described by Williams, and their relations will be discussed later.

The "trachyte" of San Magno, to the west of the lake, approaches nearer to the Bolsena rock, the silica being 60.03 but the potash is still rather low, though higher than the soda (anal. 4, p. 565). It is quite free from olivine. Plagioclase is abundant and basic, giving extinction angles up to 30° on each side of the twinning plane. The groundmass is holocrystalline and composed largely of orthoclase and plagioclase, with augite, biotite and magnetite. In it occur round spots of very feebly doubly refracting substance which closely resemble leucite. Klein comes to the conclusion, however, that these are not leucites, since only 0.28 per cent. of K_2O is extracted from the rock by HCl, but that they are of glass in a condition of strain. From his description they seem to be the same—or very similar to—certain spots in the groundmass of a leucite phonolite from Lake Bracciano, which will be described in another paper. These are of "pseudo-leucite," a mixture of nepheline and orthoclase probably due to the alteration of leucite crystals.

The "olivine-bearing andesitic trachytes" of Sassara and Mont' Alfina (Klein, p. 6) belong rather to a type of rock which will be described in the next paper than to the vulsinites. The silica is lower (56.32 per cent.) and magnesia quite high (anal. 6, page 565). Basic plagioclase phenocrysts, with extinction angles up to 30° on each side of the twinning plane are very abundant, more so than orthoclase. Olivine, augite and biotite also occur as phenocrysts. The groundmass contains little glass, and is made up of the same minerals that compose the phenocrysts, except that olivine is wanting.

Andesite.—An augite-andesite is met with as the last product of eruption at Monte Rado, west of Bagnorea, and is described by Klein (p. 32). This, it will be remembered, is one of Verri's five centers of activity, and probably poured forth at an earlier stage the leucitic lava streams met with at Sassi Lanciati, Bagnorea and Porano. It is without doubt one of the last eruptions of the Bolsena volcano. Monte Rado is described as a hill covered with scoriæ, lapilli and bombs, and the specimen examined by Klein comes from the upper part. As I could not visit the locality I quote from Klein's description.

The phenocrysts are of plagioclase, which is apparently labradorite, and shows zonal structure, augite, brown biotite and olivine. These lie in a very glassy groundmass containing fluidally arranged plagioclase laths and augite microlites. Neither nepheline nor leucite could be detected. It is possible that a small amount of sanidine may be present. Klein remarks that, though the appearance and the presence of olivine would suggest a basalt, yet that the analysis (No. 7, page 565) does not agree with this determination, and that consequently it must be called an olivine-bearing augite-andesite.

Leucite Rocks.— In our classification of these rocks we are confronted with two difficulties which render the bestowal of correct names, in so far as this is an important matter, an affair of some doubt. The first is the fact, already mentioned, that the various types grade into one another mineralogically to such an extent that the drawing of hard and fast lines is rendered in many cases impossible.

The second difficulty is the fact that two separate systems of nomenclature have been proposed by leading petrologists for some of the leucite rocks. The following are the names of Rosenbusch[1] and Zirkel.[2] An effusive rock composed essentially of leucite and orthoclase Rosenbusch calls a leucite-phonolite, while Zirkel calls it a leucite-trachyte. If nepheline is added to the above combination it becomes, according to the former a leucitophyr, according to the latter a leucite-phonolite. It is unfortunate that such a diversity should exist, especially in the double use of the name "leucite-phonolite." It is true that it is an embarrassment which seldom confronts one, since both groups are of very rare occurrence. In the present case however we are, so to speak, in their native land, and a decision must be come to in regard to the matter. Zirkel's objections to Rosenbusch's use of the term leucite-phonolite seem well grounded, since through long use one connotes the presence of nepheline with the name phonolite. Another objection which might be brought up is that the name leucite-trachyte for this group of rocks has the priority, since it was used by vom Rath[3] as far back as 1867.

[1] ROSENBUSCH, Mikr. Phys., II, 621, 1887.

[2] ZIRKEL, Lehrbuch, II, 427, 1894.

[3] VOM RATH, Zeit. d. d. Geol. Ges., XIX, 584, 1867. Cf. ROSENBUSCH, II, 621.

It is true that Rosenbusch uses the term phonolite in a very broad sense, covering the leucite as well as the nepheline rocks. The advisability of such an extension of its meaning may well be doubted. As to the term leucitophyr used by Rosenbusch, I must agree with Zirkel in his objections to it, as a name which does not convey any idea of the presence of nepheline, and conveying the erroneous idea that a porphyritic structure is characteristic of it. Further discussion of this subject is uncalled for, but the terms leucite-trachyte and leucite-phonolite will be used in Zirkel's sense.

Leucitite.—Of true leucitites there seem to be comparatively few in this region compared with others of Italy, such as those of Bracciano and Albano. Klein describes eight which belong to this group, though they all carry a little plagioclase, and Bucca also notices a few. They are basic, with SiO_2 from 48 to 50, and Ricciardi's analyses show less K_2O than we would expect to find. Megascopically they are basaltic looking, dark gray and very fine-grained and compact, with only rare phenocrysts of leucite and augite. Their micro-structure is the characteristic one, well known to most petrographers, of a groundmass made up of round spots of leucite with interstitial augite needles.

The most typical of my specimens is from a flow near the lake shore, about half a kilometer north of Bolsena. Its color is dark gray with a slightly greenish tinge.

Under the microscope it shows the typical structure. Leucite crystals are extremely abundant in the groundmass, few being of phenocrystic dimensions. With them are some large green augites, a few biotite crystals almost wholly "altered," and one or two well shaped orthoclase phenocrysts. These lie in a cement composed of colorless glass, with a felt of slightly greenish augite microlites, some magnetite grains and very few plagioclase laths.

The leucites, which show feeble double refraction, seldom reach a diameter greater than $0^{mm}.25$, and from this run down to microlitic dimensions. These smallest leucites show only rounded outlines, but those of a larger size offer more variety. While some give sharp, normal, eight sided sections, with a few small, isolated inclusions, the greater number show more or less perfect skeletal forms. Their sections consist of simple four-armed crosses; eight-rayed stars with four alternate arms larger than the intervening ones, and thick at the ends or with a short process projecting from the end on each side; six-rayed stars with thick and equally developed arms at angles of 60°; finally, sections resembling equilateral, spherical triangles in outline, generally with triangular spots of glass at the apices.

The forms are evidently due to sections of skeleton crystals, and all may be referred to leucite skeletons like those described by Senigaglia[1] in a lava of 1753 from Vesuvius. They are developed not so much along axes as along planes from the center of the crystal to all the trapezohedral edges, the crystals being really trapezohedrons with deeply sunken faces and high salient edges.

Similar forms are to be found in other Italian leucitites, as from Lake Bracciano and the Alban Hills. Pirsson[2] has observed almost identical forms in rocks from the Bear Paw Mountains in Montana and gives an interesting discussion of their growth to which the reader is referred.

Another typical leucitite comes from Sassi Lanciati (Tossed Rocks), a locality about 2^{km} south of Bolsena on the lake shore where the road passes a lava stream about 10 meters high, showing well developed columnar structure. In the early days of geology this was apparently a well-known and oft-cited locality, but more accessible and better examples of this structure have thrown it into oblivion.[3]

The rock is described by Klein (p. 21), and is very similar to the first one described in this paper. It may be noted however that the inclusions in the leucite are rings of augite microlites arranged tangentially near the borders, and that no skeleton forms are present. Plagioclase is almost wholly lacking. Its specific gravity is 2.311 at 26° C.

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[1] SENIGAGLIA, Neu. Jahrb., B. Bd. VII, 418, 1891.

[2] PIRSSON, Am. J. Sci., I, 1896.

[3] VOM RATH, op. cit., 292.

With the leucitites may be classed the rock from a flow at the Osteria di Biagio, on the road from Orvieto to Bolsena. It is rather a nepheline leucitite, as it contains considerable nepheline in the groundmass. Its rather dark greenish gray groundmass is compact, but shows some narrow vesicular cavities, generally in planes parallel to each other as determined by the flow. In the groundmass are many small clear leucite phenocrysts and a few small black augites. Into the cavities project very many small stout hexagonal prisms of nepheline, which are coated with an opaque white substance, but are clear grayish white within.

Its appearance in thin section closely resembles that of the leucitites already described, the leucites being round, with feeble double refraction, and with included rings of augite microlites. The pyroxene of the interstitial groundmass is an ægirine-augite, and the base generally exhibits faint double refraction. Examination with acids shows that this is largely nepheline, though a small amount of glass seems to be present. No crystal sections of nepheline were to be found, and in the body of the rock it acts as cement and is undoubtedly the last product of crystallization. In the groundmass a few small colorless laths were to be seen which may be referred to orthoclase, indicating a transition toward the leucite-phonolites.

As phenocrysts appear large and much cracked leucites, green augites, a few fair-sized crystals of orthoclase much broken and corroded, which are usually associated with the augite and appear to belong to the same period of crystallization, and finally a a few remains of biotite crystals altered as usual to a granular mass of augite and magnetite. The interior of one of these last contains fine parallel straight lines of minute magnetite grains lying at an angle of about 60° with the basal plane.

The leucitites described by Klein agree on the whole so closely with the above that it is needless to do more than refer to them. Analysis No. 8, page 565, of the leucitite of Sassi Lanciati, has been selected as typical of Ricciardi's closely agreeing analyses of this group. We may note here that they are low in silica, high in iron, lime and magnesia, and surprisingly low in alkalies, considering the amount of leucite present.

Leucite-phonolite.— Representing this group are specimens from two localities, which differ somewhat from each other and which may be described separately.

Two, from above St. Trinita near Orvieto, are from different parts of the same flow, one being compact while the other is highly vesicular, though not enough so to be a true scoria. The groundmass is light gray and in it lie many large, sharp leucite crystals up to $1^{\mathrm{cm}}.5$ in diameter, of a pale yellowish white color and waxy luster. They are much cracked and contain large inclusions of augite and magnetite, generally as a nucleus in the center. Lining the sharp trapezohedral cavities left by leucites which have fallen out is a thin white crust, which under a lens is seen to be minutely mammillary.

In thin section the large leucites, which have generally lost much of their substance through cracking and falling out, show quite strong double refraction. The edges of their sections are sometimes corroded, and in these places one observes that they are separated from the groundmass by a narrow border of clear colorless substance, with a refractive index slightly higher than that of the leucite. This is the white crust just mentioned. Between crossed nicols it shows weak double refraction, and in places a radially fibrous, spherulitic structure is developed, the fibers diverging toward the leucite. Definite determination could not be made, but it is probable that this border consists essentially of orthoclase, perhaps due to a solution of the leucite in the magma.[1]

The green ægirine-augite phenocrysts are somewhat fragmentary. They show distinct pleochroism; $\mathfrak{c}$ slightly bluish green, $\mathfrak{a}$ light yellowish green. A very few orthoclase and one or two labradorite phenocrysts are present.

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[1] It may be noted that in a leucite-phonolite from Latéra Bucca (p. 27) observed an apparent formation of leucite out of orthoclase, while in that from Acquapendente he notes the reverse process.

The groundmass is rather trachytic in character, as many orthoclase laths — best seen with crossed nicols — are present, showing decided flow structure. With them are numerous small leucite crystals, with rounded outlines, containing a few sporadic inclusions and an abundance of prismatic microlites of ægirine-augite, with $\mathfrak{c}_{\wedge} c = 38^\circ$. Some magnetite is also present. All these small crystals lie in a colorless base of low refractive index, which in many places shows weak double refraction, and which treatment with acid proves to be nepheline.

The other specimen of leucite-phonolite is from the large quarries immediately to the north of Bagnorea, east of the lake, whence the slabs are exported for paving stones. The same rock is described by Bucca,[1] who does not mention nepheline, though he speaks of the base as easily gelatinizable and rich in soda. It is ash gray and fine-grained, with rough texture and small cavities whose walls bear leucite but no nepheline crystals. The specific gravity was found to be 2.648 at 27° C.

Examined under the microscope the leucites and pleochroic ægirine-augites show no specially noteworthy features. The few well-shaped orthoclase phenocrysts often carry a mantle of later alkali feldspar substance like that previously described. There are also a few biotite phenocrysts which have been entirely altered to augite and magnetite in the usual way.

In the groundmass there are abundant small leucites almost free from inclusions, stout ægirine needles and some magnetite grains. Orthoclase laths are larger and more abundant than in the rock just described, and there are a few flakes of brown biotite which are among the last products of crystallization. These lie in a nepheline base similar to that of the last rock.

Klein describes a leucite-phonolite from Gradoli, northwest of the lake. Its megascopic appearance is that of a phonolite. In thin sections appear as phenocrysts a green pleochroic augite (probably ægirine-augite), some large leucites and a few sanidines. In the holocrystalline groundmass nepheline, leucite and sanidine occur in well-formed crystals, along with biotite, magnetite and apatite. A little haüyne occurs, but augite is not spoken of as present in the groundmass. There is unfortunately no analysis of this rock. Klein describes also two rocks which may belong here, one from La Canonica and one from Proceno. The former is apparently a transition type towards the leucitites, the latter is noteworthy as containing haüyne and also a very basic plagioclase. Its high percentage of silica and low lime and magnesia are also remarkable (anal. 10, page 565).

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[1] BUCCA, op. cit., 20. Also Boll. Com. Geol. Ital., XIX, 58, 1888.

The "leucitophyr" of vom Rath[1] is probably a leucite-phonolite since he mentions a colorless weakly refracting mineral as the last product of crystallization. He thinks this may be feldspar but it answers to the characters of nepheline. All of the leucitic-trachytes as well as some of the leucitophyrs, described by Bucca, probably belong here. This is shown by their augite being pleochroic, the frequent presence of haüyne, and the presence in the groundmass of a "colorless glassy base," rich in soda and easily gelatinizable (*op. cit.*, p. 19).

I may add that a specimen from Acquapendente in the collection of Yale University closely resembles my specimen, gives abundant gelatinous silica with acids, and is apparently identical with one from that locality described by Bucca. According to Scrope,[2] and apparently also according to Ricciardi[3] the lavas of Acquapendente are connected with the volcanic center of Radicofani to the north.

Leucite-trachyte proper is not definitely known from this region, though possibly one or two of Bucca's rocks belong here.

Leucite-tephrite.—Rocks belonging to this group are very abundant, and transition forms to the other types are common. Of my specimens only a few will be described in detail, as Klein's descriptions cover the ground very fully. The rocks of this group are generally of quite basaltic appearance, and resemble much the leucitites megascopically, though leucite is less common as phenocrysts than augite. Their microstructure is quite different and generally doleritic. The silica percentage is about 52.

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[1] VOM RATH, op. cit., 290.

[2] SCROPE, Volcanoes, London, 1862, 354.

[3] RICCIARDI, Terreni Vulcanici, Florence, 1879, 133.

The rock from Monte Cavallo south of Orvieto, a flow with columnar structure mentioned by vom Rath, and that from Porano, southwest of Orvieto, a flow which Verri considers as belonging to the Monte Rado center, are dark gray, fine-grained rocks showing few phenocrysts, and these small and entirely of dark green augite. Its specific gravity is 2.763 at 26° C.

Under the microscope they show a doleritic structure. In the groundmass leucite predominates as irregularly shaped crystals and patches, which correspond in function to the augite of ophitic diabase. It shows weak double refraction, with the usual polysynthetic twinning, and containing few inclusions of glass and augite. Lying between or imbedded in the leucites are long prisms of augite, together with plagioclase laths whose extinctions correspond to those of a basic labradorite. Some magnetite is also present, as well as a small amount of colorless glass. A few orthoclase laths were seen, but no nepheline could be detected.

The augite is grayish green, and shows an extinction angle of 41° with the axis *c*. Associated with it is a clear brown mineral, occurring here and there on the ends and sides of the augite crystals, and in small quantity as separate individuals of a somewhat fragmentary character, which show few crystal planes. When occurring with the augite the two are not separated sharply but shade into one another, the green color gradually giving place to the brown, the cracks running uninterruptedly through both. The mineral has a slightly lower refractive index than the augite, but strong pleochroism; parallel to *c* (assuming this to correspond to the vertical axis of the augite) it is dark hair brown, and at right angles to this, light yellowish brown and pale greenish yellow. The extinction angle with the cleavage cracks, which are quite well marked, reaches 17°.

These characters made it seem probable that we have here a growth of acmite about augite, as the last stage of pyroxenic crystallization. Further examination, however, showed that the bisectrix nearest the vertical axis is not $\mathfrak{a}$, as is acmite, but that of least elasticity $\mathfrak{c}$. The greater number of crystals are cut more or less nearly parallel to the vertical axis, but search revealed a few cases of parallel growth where the augite and the brown mineral were cut horizontally. In these the cleavage cracks of the augite formed an angle of 88°, while those of the external brown mineral formed angles of 122° with each other, the planes *b* (010) and *m* (110) being present, and the direction of least absorption being parallel to the clinopinacoid. The mineral is therefore an amphibole and may be referred to barkevikite, with whose characters it closely agrees. It is regretted that a chemical examination of this interesting mineral could not be made, but the small amount of the substance and its intimate association with the augite, rendered a mechanical separation impossible.

Bucca[1] mentions a brown pleochroic hornblende associated with the augite of a leucite-tephrite (?) from Poggio Pilato near Valentano, and also a similar amphibole in a leucite-trachyte from Casaccia on Lake Vico.[2] According to de Stefani[3] Rosenbusch observed a mineral like that described above in the "basalt" of Radicofani. Rosenbusch[4] also notes a brown hornblende surrounding augite in an Ischian trachyte.

It may be mentioned that since the chemical character of the amphibole pointed to the pyroxene being a soda-rich ægirine-augite, an examination was made to determine the character of the bisectrices of the latter. This showed that the bisectrix nearest the vertical axis was $\mathfrak{c}$, so that it is an augite.

Another leucite-tephrite from below Sta. Trinità near Orvieto may be the same as that mentioned by Klein from this locality.

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[1] Op. cit., 28.

[2] BUCCA, Boll. Com. Geol. Ital., 60, 1888.

[3] DE STEFANI, Boll. Com. Ital., 224, 1888.

[4] ROSENBUSCH, Mikr. Phys., II, 584, 1887.

It resembles the preceding, though it is much finer grained, and the leucite is seen to be quite subordinate in amount as compared with the augite and plagioclase. This last is quite basic and is a true bytownite.[1] Quite noticeable in the sections are many small flakes of brown biotite, which have given rise to patches of a bright green, finely-granular viridite, probably through atmospheric alteration. None of the other minerals show signs of decomposition, except the magnetite, which is sometimes accompanied by spots of limonite and bright orange hematite. The augite is pale gray and none of the brown hornblende is present.

Most of the leucite-tephrites described by Klein seem to resemble the above and call for no special notice. Exception must be made for those from Montalto, southwest of the lake, which Verri regards as a distinct eruptive center. They approach augite-andesites in character, but carry olivine phenocrysts, and small leucites only in the groundmass, so that Klein calls them "leucite-tephrites with accessory olivine." In mineralogical composition they correspond to a leucite-basanite, but their high content of silica allies them with the tephrites. (*Cf.* anal. 11, page 565.)

The phenocrysts are of green augite, a basic plagioclase, magmatically altered biotite, olivine, magnetite and apatite. The groundmass is andesitic in structure and consists largely of plagioclase laths, augite crystals and magnetite grains, with small colorless spots which were identified with leucite. All these lie in a glass base. It is noteworthy that in one very glassy specimen no leucite was to be found, while the other minerals remained as before.

Leucite-basanite.—None of my specimens belong here, so I may briefly mention some described by Klein as "leucite rocks of doleritic habit." All his specimens come from the southern part of the region. They are distinguished from the true tephrites by their constant olivine content and structure, and Ric-

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[1] ROSENBUSCH (Mikr. Phys. II, 762, 1887) mentions the occurrence of acid plagioclase in a leucite-tephrite from "Orvieto."

TABLE I.

	1	2	3*	4	5	6	7	8	9	10†	11	12	13
SiO_2 . .	59.22	57.97	58.21	60.03	63.26	56.32	56.42	48.89	55.10	59.69	55.11	52.16	48.09
Al_2O_3 .	18.56	17.65	19.90	17.05	16.05	18.17	16.81	16.05	19.20	16.22	16.07	15.03	13.60
Fe_2O_3 .	....	0.63	4.07	1.83	1.04	2.23	3.26	1.80	....	1.93	3.04	3.17	2.52
FeO . . .	6.06	7.50	0.87	4.15	6.13	6.47	6.92	10.09	6.86	8.17	8.46	8.42	9.36
MnO . .	....	0.09	....	0.09	0.14	....	0.23	0.43	....	0.44	....	0.24	0.10
MgO . .	1.12	1.71	0.98	1.12	1.29	2.84	3.50	3.98	1.18	2.72	3.10	4.69	6.75
CaO . . .	2.96	5.53	3.58	6.58	5.50	5.33	5.64	11.88	3.75	4.80	6.46	10.07	13.05
Na_2O . .	4.87	1.50	2.57	2.31	1.62	1.80	1.21	1.81	2.68	1.03	1.58	2.38	1.41
K_2O . . .	6.66	5.31	9.17	5.12	3.18	4.18	3.07	3.00	10.78	3.09	5.07	2.47	3.07
P_2O_5 . .	....	0.42	....	0.42	0.51	0.34	1.08	0.29	....	trace	0.75	1.15	0.41
SO_3 . . .	....	....	....	....	....	....	....	0.59	....	0.64	....	....	....
Ignit. . .	1.14	1.82	0.74	1.42	1.57	2.15	2.25	1.39	1.22	1.54	0.89	0.72	1.62
	100.59	100.13	100.09	100.12	100.29	99.83	100.39	100.19	100.77	100.27	100.53	100.50	99.98
Sp. Gr.	2.55	2.45	....	2.54	2.42	2.52	2.63	....	2.50	....	2.55	2.75	2.76

* Contains trace of TiO_2.

† Contains trace of Cl.

1. Vulsinite, Nassini's quarry, Bolsena, vom Rath, op. cit., 291.
2. Vulsinite, Bolsena, Ricciardi, Klein, op. cit., 8.
3. Vulsinite, Bolsena, No. 665, Washington.
4. Vulsinite, San Magno, Ricciardi, Klein, op. cit., 10.
5. Vulsinite (?), San Lorenzo, Ricciardi, Klein, op. cit., 3.
6. "Andesitic Trachyte," Monte Alfina, Ricciardi, Klein, op. cit., 7.
7. Augite-andesite, Monte Rado, Ricciardi, Klein, op. cit., 33.
8. Leucitite, Sassi Lanciati, mean of two, Ricciardi, Klein, op. cit., 20.
9. Leucite-phonolite (?), Nassini quarry, Bolsena, vom Rath, op. cit., 290.
10. Leucite-phonolite (?), Proceno, Ricciardi, Klein, op. cit., 26.
11. Leucite-tephrite, Montalto, Ricciardi, Klein, op. cit., 28.
12. Leucite-tephrite, Monte Bisenzio, Ricciardi, Klein, op. cit., 19.
13. Leucite-basanite, Valentano, Ricciardi, Klein, op. cit., 23.

ciardi's analyses show them to be very basic, with about 48–49 per cent. of silica.

According to Klein they are gray, medium-grained rocks, somewhat vesicular. Leucite, augite and olivine appear as phenocrysts; plagioclase is subordinate in amount both as phenocrysts and in the groundmass. Klein remarks that as olivine increases plagioclase decreases, though this relation has apparently no influence on the structure. The groundmass is made up largely of augite, with leucite, magnetite and plagioclase, occasionally biotite and haüyne, and in one instance nepheline. The presence of a glass base is not mentioned.

Chemical composition.—A selection of what seems to be the best and most typical of Ricciardi's analyses is given in the table, together with the two of vom Rath. No. 3 was made by myself in the Mineralogical-Petrographical Laboratory of Yale University, with the assistance of Professor L. V. Pirsson. I gladly take this opportunity of expressing my sincere thanks to him for his valuable assistance and advice. The general discussion of the analyses will be reserved for the final paper of the series.

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